search strategy, I located 288 primary studies, published in 1973–2002, which reported mean MWT scores for 527 groups of German, Austrian, and Swiss study participants (healthy adults as well as patient samples), totaling nearly 29,000 subjects. This large-scale meta-analysis of unrepresentative samples yielded an ΔIQ estimate of 2.61 for the gC measure MWT. This figure is comparable with the finding from the Austrian psychiatric patient sample and further nicely dovetails with extant evidence from population-based studies. Flynn (1984) originally arrived at a ΔIQ estimate of about 3 (USA, 1932–1978), which was later updated to about 2.5 (USA, 1972–1995 [Flynn 1998c]). A reanalysis of the extant international evidence by Storfer (1990, p. 439) suggests that ΔIQ was about 3.75 during the first quarter of the twentieth century, about 2.5 for the subsequent decades until about the mid-1960s, and probably less since then.

To summarize, Blair's claim of a gF–gC dissociation supposedly seen in the Lynn–Flynn effect (in order to support his gF' concept) is neither supported by the empirical record in this area nor by the new findings presented here. We are all well advised not to devote ourselves to phlogiston theories of human intelligence.

How relevant are fluid cognition and general intelligence? A developmental neuroscientist's perspective on a new model

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Abstract: Blair boldly proposes a model integrating different aspects of intelligence. Its real-life value can be put to the test by using programs designed to develop children's abilities in areas predicted to be crucial for minimizing adverse outcome. Until support from such programs is available, the model is an interesting hypothesis, albeit with remarkable possible repercussions. As such, it seems worthy of further development.

In his target article, Blair provides a comprehensive model for identifying and describing different aspects of intelligence (broadly defined), including the neurobiological underpinnings. As with many models proposed, a developmental neuroscientist is tempted to ask: So what? Numerous models are out there, aiming to describe and explain the multitude of observations regarding "intelligence" both in impaired and unimpaired subjects. What makes this work stand out is the direct applicability of the concept and, even better, the fact that we are liable to put it to the test both clinically and in neuroscience research. Clinically, those working with children from disadvantaged backgrounds or with children showing mental retardation can direct their attention towards developing programs aiming to influence the specific aspects of fluid cognition that Blair hypothesizes to be central in determining later outcome, as measured by as yet inappropriate tests. For neuroscience research, a number of directions seem to suggest themselves as to how the pertained distinction of fluid and general intelligence could be disentangled, for example, by using modern neuroimaging methods. As it is, the target article describes a bold new concept, thoroughly doing away with the monolithic idea of *g*-and-nothing-else. As such, it is likely to draw criticism from "proponents of the old order," and probably rightly so. However, programs designed to test the concept can (and, hopefully, will) be developed that enable supporting the concept with not only theoretical neuroscience data (such as functional magnetic resonance imaging [fMRI]) but, ideally, with the very practical and highly important result of children simply doing better in life. If this were the case, Blair must be commended for boldly going down this road. If not, then it will be just another model, with not much relevance for clinicians' daily work.

There are drawbacks, of course. What about the role of the thalamus and the cerebellum, both of which have been considered cornerstones for the cognitive impairment seen not only in schizophrenia (Clinton & Meador-Woodruff 2004; Rapoport et al. 2000; Schultz & Andreasen 1999)? Considering that the thalamus was classically used to define prefrontal cortex as the projection area of the mediodorsal thalamic nucleus, should it not be expected to play some kind of role, as a gatekeeper or in some other form, hitherto unknown? In our study on gray matter correlations with a broad measure of intelligence, the thalamus was implicated in these correlations in a connectivity analysis, as was the medial temporal lobe (Wilke et al. 2003). Interestingly, the correlation of global gray matter and IQ (as assessed by the Wechsler batteries and thus reflecting mainly general intelligence) only develops during childhood, perhaps lending support to the notion of fluid skills playing a larger role in early childhood. Also, if there is a dissociation of fluid skills and general intelligence in adults in a way that only fluid skills are affected, should there not also be a model for an isolated decrease in general intelligence which could shed additional light on the issues? Finally, could the differential effects of prefrontal cortex lesions in the neonatal period and in adulthood not also be seen as simply being an indication of the generally larger cortical plasticity in children? I am sure others will come up with more, and more serious, issues this model has to accommodate, and this process will be interesting to follow.

Still, it also seems interesting to complement this work with two timely studies published recently. In one fMRI study, Breitenstein et al. (2005) distinguished good learners from bad learners by the amount of hippocampal activation. This is all the more interesting as all subjects were healthy adults, indicating that, employing the right kind of paradigm and using performance data as a guide, it may be possible even in healthy subjects to tease out the different aspects of cognition described by Blair. Even more interesting and lending strong support for one of the main theses of the target article is the study by Heinz et al. (2005). Here, subjects with three genetically defined variants of a serotonin-transporter system were investigated by using fMRI and applying the concept of functional connectivity. This serotonin transporter is believed to play a crucial role in a subject's liability to develop major depression. It could be demonstrated that the strength of the coupling between the amygdala and the ventromedial prefrontal cortex is a function of the genetic variant of the subject. Therefore, a genetic influence on behavior via the pathway that plays a crucial role in Blair's model of cognition-emotion reciprocity is suggested. This adds evidence for a genetic contribution to or modulation of the putative environmental influence that Blair hypothesizes, which (by virtue of lending support to the mechanism in itself) further strengthens the point made about this link.

Overall, I believe this to be a very interesting model which accommodates a number of observations and lends itself to rigorous testing. As it is, however, its virtues, beyond explaining the observed, can be assessed only in years to come, following extensive discussions of the pros and cons. It is as yet too early to decide, but for the sake of children possibly profiting from a more targeted approach to support, I wish the model well.

Can fluid and general intelligence be differentiated in an older adult population?

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Abstract: The question of whether fluid intelligence can be differentiated from general intelligence in older adults is addressed. Data indicate that the developmental pattern of performance on fluid tasks differs from the pattern of general intelligence. These results suggest that it is important to identify changes in fluid cognitive functions associated with frontal lobe decline, as they may be early indicators of cognitive decline.

It has been suggested that fluid intelligence and general intelligence can be differentiated both in terms of neurobiology and cognitive performance (Blair's target article; Duncan et al. 1995; Kane & Engle 2002). Although researchers show increasing interest in understanding the differences between types of intelligence, the practical implications of this potential dissociation has been poorly addressed. Blair focuses on child development and suggests that fluid intelligence, compared with general intelligence, may be affected by different developmental experiences and different cortical processes. Most importantly, Blair stresses that the assessment of fluid intelligence skills may provide us with unique insight into early mental development and how this relates to adaptive success in children from varying social and economic backgrounds.

The relationship between fluid intelligence and general intelligence is particularly compelling in both early childhood and late adulthood, given the neurobiological changes that take place during each period. Specifically, the late development of the prefrontal cortex (PFC) in children/adolescents and the relatively early atrophy of the PFC in late adulthood suggest that during these stages, unique dissociations between general intelligence and fluid intelligence may be the most robust (Leigland et al. 2004). We emphasize the role of the PFC, given that one of the first studies to detect the fluid intelligence–general intelligence dissociation focused on patients with PFC injuries (Duncan et al. 1995). In Duncan et al.'s (1995) research, patients with PFC injuries obtained above-average full-scale IQ (FSIQ) scores on the Wechsler Adult Intelligence Scale (WAIS) compared to the control group. However, when given a test of fluid intelligence, their performance was significantly below that of control participants. Similarly, Fry and Hale (1996) found fluid abilities to be specifically impaired in patients with frontal lobe damage, whereas crystallized abilities were intact. Kane and Engle (2002) interpreted this dissociation as possibly reflecting the fact that standardized intelligence batteries average performances across subtests varying in their assessment of fluid intelligence versus crystallized intelligence, potentially diluting the effect of PFC insult on fluid intelligence. Blair and others have noted that findings from these clinical studies assessing frontal lobe damage are provocative, but only speculative due to the small sample sizes used.

Given these results, a relevant question to ask is whether this pattern is present in normal development. Could performance on fluid tasks in early development (when the PFC is immature) and late development (when the PFC is declining) show the differentiation seen in patients with damage to the prefrontal cortex, between general intelligence and performance on fluid/executive ability tasks? Recent work in our lab has found that across development, executive function performance seems to correspond to the development and decline of the PFC (see Fig. 1). This U-shaped pattern of executive ability/fluid scores across development contrasts studies assessing general intelligence which show that performance remains developmentally stable across the lifespan (Horn 1970).

Our data, along with those of others, suggest that the issues that Blair addresses in early development may also be relevant in late adulthood. This may be specifically true in determining whether fluid intelligence measures provide us with unique insight into cognitive decline associated with aging, and whether these measures are distinct from general intelligence measures in their ability to predict clinical outcome and success in everyday living. To assess the dissociation between frontal measures and psychometrically defined global measures previously noted in PFC patients, with a larger and more generalizable sample, we chose to focus on older adults. Increasing evidence indicates a decline in frontal lobe functioning with age (e.g., Braver & Barch 2002; Bunce 2003; Haug et al. 1983; Raz 1996; Raz et al. 1993). Isingrini and Vazou (1997) found that performance on frontal lobe tasks correlated with measures of fluid intelligence but not crystallized intelligence in a group of older adults. Schretlen et al. (2000) hypothesize that "age-related atrophic changes in frontal brain structures undermine the functioning of executive abilities, and this results in the gradual

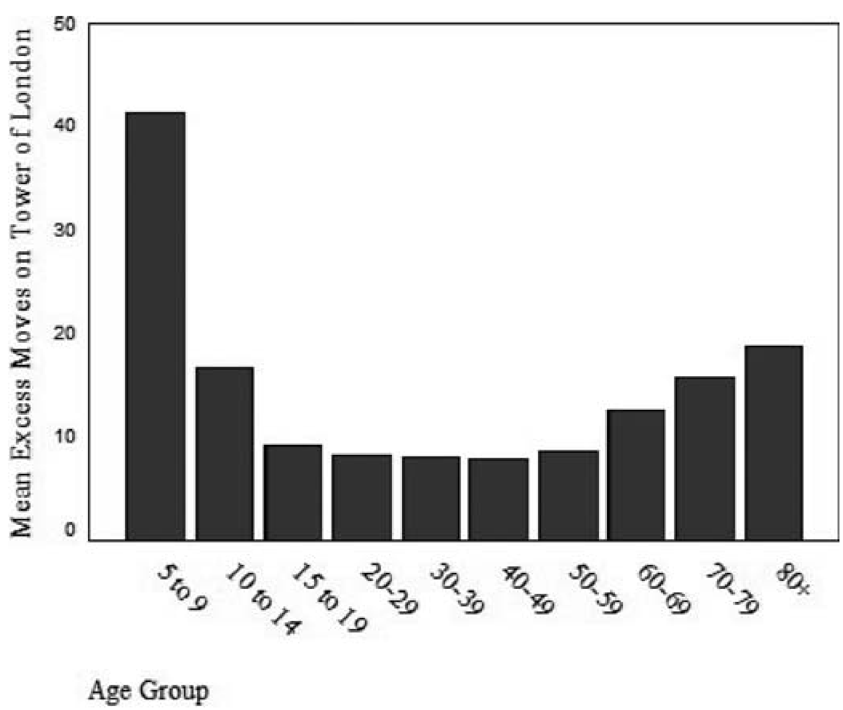

Figure 1 (Zook & Davalos). Performance on the Tower of London, an executive ability task, throughout the life span.

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decline of fluid intelligence" (p. 53). Schretlen et al. found that age-related declines in executive ability and frontal lobe volume accounted for a significant amount of variance in fluid intelligence and revealed a significant negative correlation between fluid intelligence and age. Using various measures of intelligence, we have found converging evidence that indicates that, while crystallized intelligence remains stable, fluid intelligence and executive function performance decline with age, with the most prominent decline beginning in the 60s (Zook et al., in press). In another study looking specifically at older adults, we found that although full-scale intelligence scores in our sample of older adults were above the population mean of 100 and significantly higher than in the younger adult group, the older adults' performance on a fluid intelligence task was significantly below that of the younger adults. Performance on two executive ability tasks, the Tower of London and the Wisconsin Card Sorting Task, were also significantly lower in the older adult group.

These results support Blair's proposal that a neurobiological model is needed that differentiates cognitive processes associated with the PFC from a general, psychometrically defined general intelligence across the life span. It is important to understand the specific developmental aspects of fluid intelligence (e.g., late development and early decline of the PFC) not only as part of a theory of cognitive development, but also in terms of neuropsychological assessment and intervention. Following from the ideas presented by Duncan et al. (1995), Kane and Engle (2002), and our data, we suggest that intelligence batteries such as the WAIS and WISC may not identify specific types of impairments in cognitive functioning associated with fluid intelligence. Blair points out that it is important to study cognitive function and variations in performance by using a neuropsychological and psychometric framework and to look at development in typical as well as atypical populations. It is also suggested here that when studying and assessing cognitive function across the life span, multiple measures of fluid intelligence should be used in addition to more general measures of intelligence. Such an approach could identify functional cognitive differences and allow for the implementation of interventions both developmentally and in late adulthood.

Author's Response

Toward a revised theory of general intelligence: Further examination of fluid cognitive abilities as unique aspects of human cognition

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Abstract: Primary issues raised by the commentaries on the target article relate to (1) the need to differentiate distinct but overlapping aspects of fluid cognition, and (2) the implications that this differentiation may hold for conceptions of general intelligence. In response, I outline several issues facing researchers concerned with differentiation of human cognitive abilities and suggest that a revised and expanded theory of intelligence is needed to accommodate an increasingly diverse and varied empirical base.

R1. Introduction

A number of important issues and challenges are raised by the commentaries on the target article, which need to be addressed. It is worth noting at the outset, however, that most of the commentaries are in agreement with the need to clearly differentiate fluid cognitive abilities from general intelligence. All but one or perhaps two of the commentaries take the position that there is something to be gained by such differentiation, and really none presents an all-out defense of *g*, the general factor of intelligence, in an attempt to discredit the target article's primary thesis. This is of considerable interest and perhaps suggests that reliance on the explanatory power of the mathematically derived general factor in research on human intelligence is appropriately on the wane. Certainly the scientific foundation on which the general factor rests is very clear, and it is without question one of the most enduring constructs in the history of psychological research. However, the individual differences framework for the construct is inherently limited by its correlational nature and, despite its claims to comprehensiveness, has not been able to provide a well-grounded explanation for the aspects of human behavior with which it is associated. Accordingly, I suggest that the general factor in its familiar form is headed for the margins of scientific inquiry because of a fundamental lack of specificity. But whether the construct will go, in the immortal words of T. S. Elliot, "not with a bang but a whimper," or whether Samuel Clemens' "the report of my death was an exaggeration" will prove a more apt characterization of the future of the general factor as an aspect of research on intelligence, is certainly open to question.

Although one could argue endlessly about whether the construct of general intelligence in its familiar form will or will not fade from the scientific limelight, it is my opinion, and I think that of many others, that the decline of the explanatory power of the general factor has been apparent for some time. The relevant question is how to best fit new data and insight into the old order of *g*. This is really the core of scientific change in the sense of Thomas Kuhn (1962). How can we best go about instantiating change in the study of human cognitive abilities within the time-honored framework of *g*? In part, it is the variety of ways in which this may be accomplished that lies at the heart of the issues raised by the commentaries.

In this response, I examine some logical next steps in revising the theory of general intelligence to accommodate an expanded view of fluid cognition. In doing this, I first respond to commentary focusing on theory development and the expansion of the empirical base in research on intelligence. I then turn to what I think are some of the key issues facing researchers concerned with the differentiation of fluid cognitive abilities from general intelligence. Here I examine definitional issues and address concerns regarding the unity versus diversity of executive function (EF), working memory (WM), and fluid intelligence (gF). In response to commentators suggesting the need for greater differentiation of EF, WM, and gF, I outline evidence in support of an integrated fluid cognitive construct. In this, I also examine the role of attention in fluid cognitive functioning and juxtapose the model presented in the target article with John Duncan's

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